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1 Introduction

"When we interact with one another", Norman (1993: pp. 81–82) writes, "we have to transform our thoughts [let's say also our 'mental representations'] into surface representations [e.g. words, gestures, objects] so that others can have access to them." Norman illustrates this idea by giving a virtual example of a person — Henri — who had a car accident, and who relates it to his friends like this:

> "'Here,' Henri might say, putting a pencil on the tabletop, 'this is my car coming up to a traffic light. The light is green, so I go through the intersection. Suddenly, out of nowhere, this dog comes running across the street.' With this statement, Henri places a paper clip on the table in front of the car to represent the dog. 'I jam on my brakes, which makes me skid into this other car coming from the other direction. We don't hit hard, but we both sit there stunned.' [...]" (Norman, 1993: pp. 47–48.)

In Henri's relation, the tabletop, pencils and paper clip (among others) are artefacts used to represent real objects such as the street, the cars and the dog. These surface representations, we will say, allow one to make oneself understood, that is, they are "representations for self-understanding". The same representations, Norman adds, are also "a tool for social communication: Several different people can share the tabletop and the story at the same time, perhaps suggesting alternative courses of action". For example:

> "'Look,' Marie might say, picking up one of the pencils, 'when you saw the dog, you should have gone like this.' 'Ah, but I couldn't,' Henri might respond, 'because there was another car there,' and he puts yet another pencil on the tabletop.'" (Norman, 1993: p. 48.)

In this collective relation, the tabletop becomes "a shared workspace with shared representations of the event." In this situation, the surface representations, we will say, are "representations for mutual understanding", i.e. representations providing "a shared and explicit ground for communication" (Ostwald, 1996).

[1] The theoretical framework presented in this chapter was proposed and developed by the second author Alain Giboin, i.e. the application of Ostwald's model of "representations for mutual understanding" leading to the notion of "representations for mutual agreement".

Although hypothetical and simple, Norman's situations of an accident report give an idea of multiple representations (internal and external) used in groups. Our aim in this chapter is to explore further multiple representations in groups, by considering real and complex situations of accident reports. The situations considered here are those where car accident specialists, or *accidentologists*, analyse accidents cooperatively to explain them, and to produce an accident report (or accident folder). Our analysis of the multiple representations used by the accidentologist's teams is based on the model of "representations for mutual understanding" proposed by Ostwald (1996) and which accounts for software designers' activity. To some extent, the accidentologists' activity can be considered as a design activity, a "retrodesign" activity, i.e. reconstruction of the accident. This activity can in turn be considered as a kind of problem solving. That is, accidentologists have to reconstruct some event which occurred in the past. We aim in this chapter to assess the validity of Ostwald's model for the accidentology situations, and consequently to establish a basis for a future model of collective representation management in accidentology.

We first present the domain of accidentology, the method and theoretical framework used to study the representations and their management in the accidentology teams. We then describe a number of dimensions and attributes of the multiple representations used in the accidentologist's teams that emerged from our analyses. Furthermore, we will look at some aspects of multiple representation management in the accidentology teams, including cooperation and collaboration among accidentologists. To conclude, we discuss some of the consequences of our results on several issues of multiple representations evoked in this volume.

2 Domain, Method and Theoretical Framework

2.1 The Domain of Accidentology

The accidentologist's teams that we studied belong to the Department of Accident Mechanism Analysis of INRETS (the French National Institute for Transport and Safety Research). These teams are multi-disciplinary, and they associate researchers and investigators from different specialities covering the components of the driver–vehicle-infrastructure (DVI) system, i.e. infrastructure engineers, vehicle engineers, psychologists (who could be called "driver engineers"). The DVI system helps the accidentologists in their analysis and understanding of the accidents (see section 3.1).

The tasks of the accidentologist's teams are:

1. to analyse the malfunctioning mechanisms that occur in the DVI system, and which generate road accidents;
2. from those analyses, to elaborate diagnoses as a mean for improving transport safety;
3. from those diagnoses, to help in designing infrastructure and vehicles, to train infrastructure and vehicle designers, road planners and users.

Teams of investigators perform the first task. The investigators operate at the site of the accident along with the emergency and police units. Usually, when there is an accident, INRETS is called immediately, having been informed by the fire crew. In general, a team of two investigators is formed: one is responsible for interviewing the drivers involved in an accident, while the other is responsible for gathering information on the accident itself (e.g. photos of the cars, records of the tracks left by the vehicles). They then exchange their first impressions of what happened and their first hypotheses. They determine what information is missing which will lead to an additional brief. The investigators then write a synthesis report. Based on these data, a kinematics analysis is performed (Lechner et al., 1986; Lechner & Ferrandez, 1990). This phase aims at identifying the movements of the vehicles involved in the accident, e.g. their positions, speed and acceleration. The final brief includes the synthesis of the accident, ending the pre-analysis (Ferrandez et al., 1995).

The second and third tasks are performed by researchers. Researchers use the briefs elaborated by the investigators to perform these tasks. The second task is also called thematic analysis (Van Elslande, 1992). An example of a thematic analysis is that of drivers of small fast cars of the GTI type (Girard & Michel, 1991a, b).

Investigators have to cooperate to interpret specific road accidents and produce the related accident folders. Researchers have to cooperate with investigators so that investigators can produce relevant accident folders and so that researchers can exploit these accident folders for their thematic analyses.

2.2 *Method*

2.2.1 Data Collection

Accidentology data were collected from three kinds of source constituted initially for a study aiming at designing a computer system to support the accident analysis task (see Alpay et al., 1996; Alpay, 1996; Dieng et al., 1996). The sources are:

(a) INRETS reports, papers and books, e.g. on models of accidents (Fleury, 1990; Fleury, Fline & Peytavin, 1991).
(b) Interviews with a limited number of accidentologists. The purpose of the interviews was to get a description of how accidentologists view their tasks.
(c) Transcriptions of experimental accident case analyses performed by pairs and trios of accidentologists from the selected set. The purpose of the case analyses was to get an account of how accidentologists actually perform their tasks, especially how they produce the scenario of a specific accident, and how they identify the factors that determined this specific accident.

The accidentologists who were interviewed and observed were mainly researchers, and more precisely: two psychologists (E-psy1 and E-psy2), two vehicle engineers (E-veh1 and E-veh2), and three infrastructure engineers (E-infra1, E-infra2 and E-infra3). Note that the majority of these researchers had been investigators in the past. Both psychologists had conducted interviews of the drivers involved in an accident, just after the accident, and analysis of such interviews through discussions

with the vehicle engineers or the infrastructure engineers who had recorded the vehicle tracks and taken photos of the infrastructure. The vehicle engineer E-veh1 had focused on the record and the analysis of the tracks left by the vehicles on the pavement. The two infrastructure engineers, E-infra2 and E-infra3, had been investigators, but only E-infra3 was still practising. E-infra1 had never worked at the scene of the accident.

In this chapter, we will make frequent references to one of the accident case analyses we observed. This analysis involved E-psy1, E-veh2 and E-infra3 who studied the following accident case:

Case 003 (see Figure 1). The accident happened on a national road, with three lanes; the central lane being non-allocated, i.e. cars coming from both directions can use the central lane. The accident occurred at night between three cars: a Toyota Sunny, a Renault 21 and a Nissan Micra. The driver of the Sunny was driving on the right lane. He urgently needed to get gasoline. When he saw a petrol station on the left side of the road, he crossed the three lanes to get to the station. The driver of the Renault 21, who was at that moment overtaking a car and thus was on the central lane, crashed into the Sunny. The driver of the Micra, who was coming from the opposite side of the road, also crashed into the Sunny.

2.2.2 Data Analysis

The analysis of the collected data consisted of identifying the multiple representations and the processes of multiple representations management, using the theoretical framework described in the next section.

2.3 *Theoretical Framework*

Our analysis of multiple representations in the accidentology domain is based on the work of Ostwald (1995, 1996) on supporting collaborative system design with representations for mutual understanding. According to Ostwald, in collaborative design, a shared understanding between designers is necessary to coordinate work efforts. A special case of collaboration occurs when designers and users design together. In this case, the necessary shared understanding must be created in spite of great communication difficulties.

To address the problem of shared understanding between designers and users, Ostwald proposed an approach that emphasises the construction of representations to facilitate communication among partners, or representations for mutual understanding. Representations for mutual understanding are artefacts for constructing individual and shared understandings. That is, they are external representations, i.e. some "explicit expression (e.g. verbal utterance, diagram, computer code) of some idea".

In this model, representations are said to have meaning "only in the sense that they are interpreted by someone, or something (such as a computer)". Agents interpret

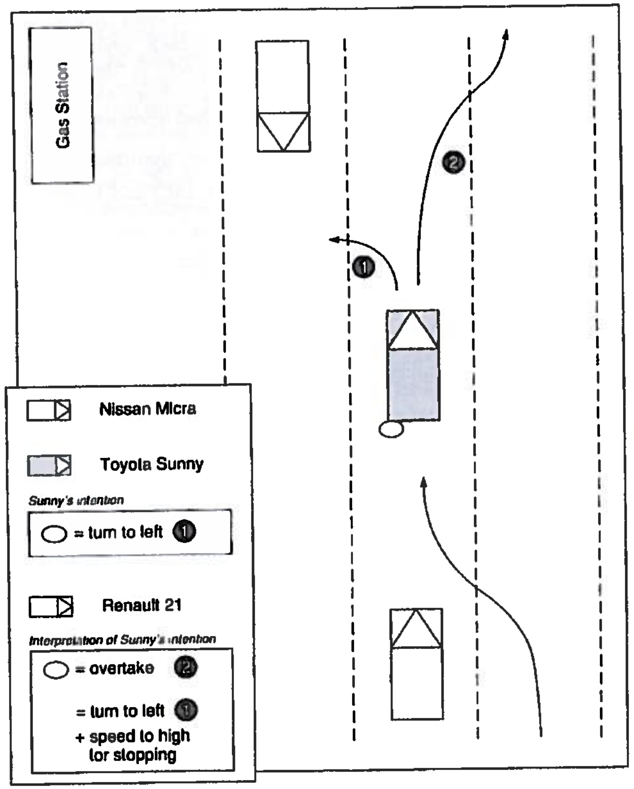

Figure 1: Accident case

representations "within a social context and against their individual background". Between members of a common culture, representations are produced (by the so-called "speakers") and understood (by the so-called "listeners") "against a rich background of shared experiences and circumstances". When speakers and listeners have a different culture, they have little shared context, or they have a different context (see Figure 2a). Such non-shared context is largely tacit and cannot be completely described or expressed. This leads to communication breakdowns. On the contrary, when the speaker and the listener share (i.e. intersection) more context (see Figure 2b), they lessen the risk of mismatch between the speaker's meaning and assigned meaning by the listener.

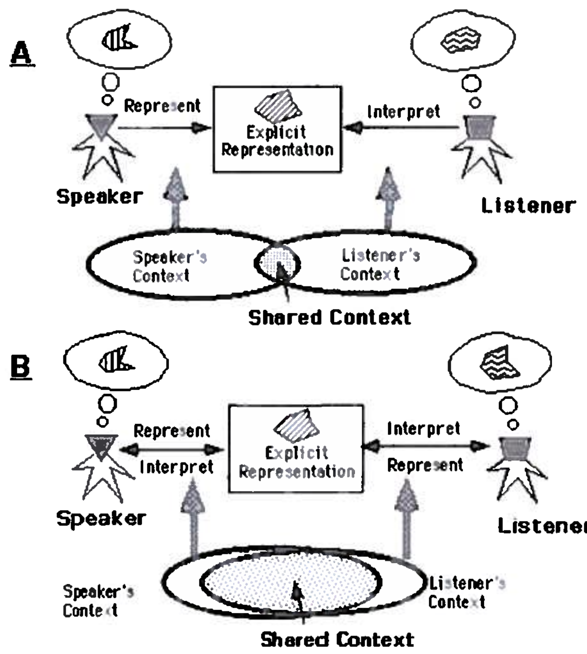

Figure 2: The role of shared context in communication (Ostwald, 1996). (A) Problematic situation: breakdowns in communication occur when there is little shared context between speaker and listener. (B) Desired situation: a shared context ground communication between speaker and listener

According to Ostwald, external design representations can help to establish such a shared context for communication. These representations provide referential anchoring (Clark & Brennan 1991; see also Bromme & Nückles, chapter 10) as an object that can be pointed to and named, helping partners to make sure they are talking about the same thing. Grounding communication with external representations helps to identify breakdowns and serves as a resource for repairing them.

Finally, representations for mutual understanding support three processes. (1) They support the *activation* of tacit and distributed knowledge by providing an object that may be reacted to. For example, descriptions of current work practice can activate domain knowledge when developers and users make the descriptions the focus of discussion. (2) They provide a shared and explicit ground for *communication*. As representations are created and discussed this common ground accumulates. (3)

They support *envisioning* of future work practices by communicating developer's ideas in a form that can be experienced by users, rather than merely imagined.

As we will see in the remainder of this chapter, Ostwald's model needs to be complemented or modified to account for the multiple representations used by the accidentologist teams. Thus, we used other existing theoretical elements, in particular:

(a) the *Common Ground* model of Clark (1992), which is referred to by Ostwald through Clark and Brennan (1991), and on which is based the chapter by Bromme and Nückles (chapter 10);
(b) the *Computational Model of Multiple Representations* (CaMeRa) of Tabachneck, Leonardo and Simon (1997), on which is based the chapter by Tabachneck(-Schijf) and Simon (chapter 11);
(c) Sumner's (1995) description of *Multiple Design Representations*. Sumner, a colleague of Ostwald, observed that a major part of a designer's job is to create and evolve external representations of the design being constructed, to facilitate communication and collaboration with each partner. Sumner called these representations, "multiple design representations". She noticed that these representations are tailored to the special needs of each of the major partners of the design team.

3 Types of Multiple Representations Used in Accidentology Teams

In the context of cooperative software design, Ostwald (1996) proposed a spectrum of (external) representations for mutual understanding, including text and graphics, scenarios (describing what a system should be, e.g. what tasks it should support and what steps are necessary to accomplish a task), simulation games and prototypes (determining how the system tasks can be performed). This spectrum can help to account for accidentology representations (e.g. accidentologists use text and graphics, scenarios and so on). However, it is not enough, and a more refined typology is necessary. At present, we have only some possible dimensions and features of such typology.

3.1 Dimensions of Multiple Representations

Several dimensions can be elicited from our analyses to describe the multiple representations used in the situations of accidentology we studied. Actual representations combine these dimensions. Some examples of such dimensions are given below.

3.1.1 Internal External

A first dimension is the distinction between external and internal representations, or "between information in the environment and information in the brain" (Tabachnek et al., 1997), or between "Knowledge in the head — what we can remember, what we know how to do" and "Knowledge in the world — representations we create to help visualise, understand and remember things" (Norman, 1993). Accidentology situations involve both external and internal representations of information, e.g. the "DVI system" (which can be used both as an external and internal representation of information).

DVI system (Figure 3): The DVI system has three interacting components: (1) D: the driver, (2) V: his/her vehicle, and (3) I: the infrastructure (the road and its surroundings) within which D and V circulate. In some accidents more than one driver and more than one vehicle may be involved, and are thus included in the DVI system. The different components are interrelated in their actions. For instance, the driver takes information from the dynamic environment, or the driver behaves in a certain way affecting the vehicle directly and indirectly. Furthermore different vehicles may respond in different ways to the conditions of the road. In a normal situation, the three components of the DVI system, the driver, the vehicle and the infrastructure interact in accordance. However, an accident which occurs is the result of the malfunctioning between these elements of the DVI system. Aspects such as the driver's behaviour, the state of the car and the setting of the infrastructure have to be taken into account.

3.1.2 Abstract Concrete

In the domain of software design, Sumner (1995) showed that design partners use representations at various levels of abstractions. The abstract concrete dimension refers to the distinction between concrete and abstract representations. In accidentol-

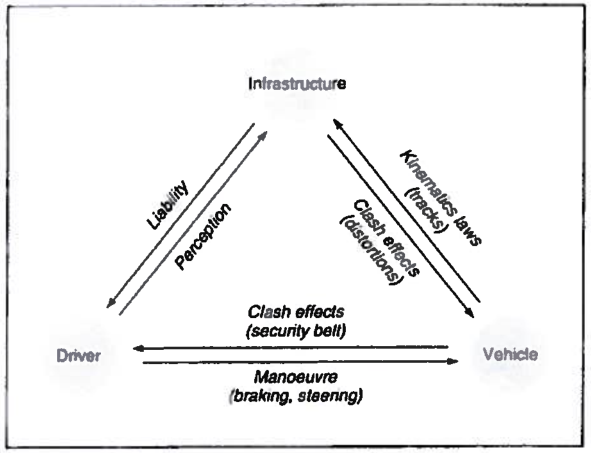

Figure 3: The DVI system

ogy, *concrete representations* are, for example, photos of crashed vehicles, photos of car crash tests (see Figure 4), photos of car tracks, textual transcriptions of drivers' interviews. *Abstract representations* are, for example, the DVI model (see Figure 3) and the functional model of the driver (see Figure 6).

Linked to this dimension is the notion of forming abstractions. In accidentology, experts in their problem-solving task have to handle various forms of information, be it "raw" data, e.g. night (the accident happened at night), or "subjective" information such as the views of the investigator on the accident. As in many other problem-solving domains (e.g. medical problem solving), in accidentology, the experts have to transform problem data supplied in the accident folder into a set of factors which explain the accident. Furthermore, owing to the interdisciplinary nature of the accidentology domain, the experts have to combine knowledge about various aspects of the accident (e.g. the car, the infrastructure and the driver). The expert's speciality will of course determine which aspect is more developed.

3.1.3 Permanent Temporary

Permanent representations are not tied up with a specific accident case and they are reused for processing several accident cases. They are already part of the specialist's expertise. Examples of such representations are: the DVI system, generic scenarios constructed from past analyses and the model of decomposing the accident into phases.

Figure 4: Photo of a car crash test

The model of decomposing the accident into phases (see Figure 5) includes different situations such as: (i) the driving situation before the accident; (ii) the accident situation, usually created by an unexpected element; (iii) the emergency situation which occurs just seconds before the crash point, and can only be solved by avoidance manoeuvres, and (iv) the actual crash point and its consequences. Some experts personalise this model by introducing an approach situation and a pre-accident situation.

In contrast, *temporary representations* are representations which are built dynamically in the task of analysing a specific accident. In this situation, the expert progressively constructs the course of the accident using the clues which are salient, and so on. Among such representations, some may be instantiations of a permanent representation. Others may be built specifically for the case at hand. Table 1 gives an example of the content of such temporary representations.

3.1.4 Shared Non-shared

The shared non-shared dimension is the most crucial dimension to account for multiple representations in groups. *Shared representations* are representations that:

(i) are used by several agents;
(ii) seem to characterise accidentology independently of any discipline aspect and any given accident;
(iii) overlap across the agents' specialities;
(iv) are similar enough to be considered as variants of the same representation;
(v) are more or less agreed among the agents. Some domain models are instances of shared representations. For example:

The functional model of the driver (see Figure 6). This model is aimed at describing, from the point of view of the driver, the mechanisms that probably caused the accident and at explaining the possible driver's malfunctionings. The model decomposes the functioning of the driver into four main activity phases: information acquisition, information processing, decision of action and action.

It is worth noting that even with common shared representations, communication between experts is not automatically smooth and spotless. For example, the experts have different terminology viewpoints on the notions of scenario and factor (see section 4.2).

The opposite of shared representations, some domain models are specific to a discipline and can be viewed as *non-shared representations*. For example:

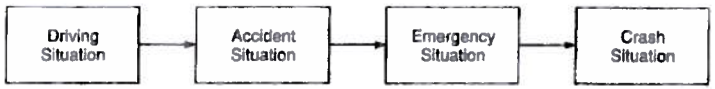

Figure 5: The permanent model of decomposing the accident into phases

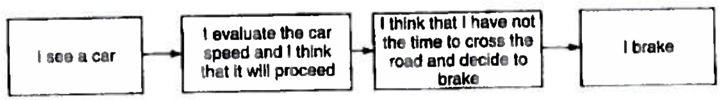

Figure 6: The shared functional model of the driver

- Only the vehicle engineers made explicit a model of vehicle's mechanical defaults and a model of kinematics sequences.
- Car tracks are mainly exploited by the infrastructure engineers and by the vehicle engineers.
- The cognitive models of the driver are typical to the psychologists and to most of the infrastructure engineers (e.g. regarding the influence of the infrastructure on the road user's behaviour). Within a given discipline, we can also take into account the specific models acquired by an expert thanks to his thematic research. For example, E-psy1 has a model of drivers' malfunctioning (see Figure 7) and a model of help to driving while the other psychologist, E-psy2, has a model of the cross-road driver and of the GTI vehicle driver.
- The detailed models of infrastructure are specific to the infrastructure engineers. Incidentally, one of the psychologists, E-psy2, has an expertise due to his thematic analyses on the drivers in cross-roads, and this expertise appears through his deep

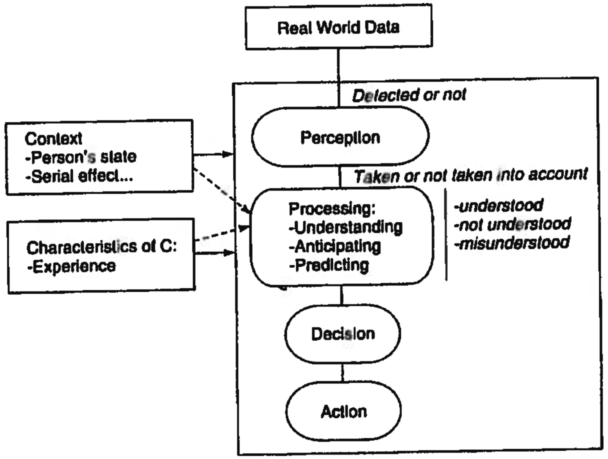

Figure 7: The non-shared functional model of the driver of E-psy1

knowledge of cross-roads. The models built by E-psy2 are specific in that they describe the infrastructure (cross-roads) as it is used by drivers.

- Models of reasoning strategies (including strategies for searching an hypothesis, for filtering an hypothesis, for testing an hypothesis) were elicited from three experts (two psychologists, E-psy1 and E-psy2, and one infrastructure engineer, E-infra3) (Alpay, 1996). Each model of how the reasoning strategies were applied, reflected the specificity of the individual expert. For example, for E-psy2 and E-infra1, the hypothesis generation was found to be a two-step process: an explication of mechanisms and an explication of factors. However, E-psy1 did not focus on the factor generation, as for him a mechanism concerned hypotheses (on the malfunctioning) and the factors which led to them. In spite of certain differences, preliminary results also show that all the experts applied the set of given strategies.

3.2 Features of Collective Multiple Representations

As previously stated, the shared non-shared dimension is crucial to account for multiple representations within groups. It characterises the "collectiveness" of representations. Thus, a key issue is to determine more specifically what features make a representation collective. One way of determining this is to explain the reason for sharing representations.

According to Ostwald (1996), the function of multiple representations is to achieve *mutual understanding*. For designers and users, Ostwald argues that to collaborate in design means to come to a mutual understanding of a design solution. Our analysis of accidentology situations showed us that the function of multiple representations is to achieve both mutual understanding and *mutual agreement*. Partners in accidentology have not only to understand why an accident happened, but also to agree on a mutual interpretation of the accident; they have not only to explain understand interpretations of accidents, but also to justify accept these interpretations. In other words, to be said to be "collective", multiple representations have to "possess" understandability features (e.g. clarity, perspicuity, accuracy) and acceptability features (e.g. soundness, plausibility, consistency, relevance) (see Giboin, 1995).

4 Multiple Representations Management in Accidentology Teams

Describing multiple representations management is answering questions such as: Which goals do agents want to achieve in this management? Which operations do they perform, with which tools? Which factors determine management? Answers provided by Ostwald (1996) in the context of cooperative software design can help account for accidentology "retrodesign", i.e reconstruction. However, these answers must be adapted or complemented to take into account the specificities of the accidentology domain.

4.1 Goals of Multiple Representation Management

At a higher level, the management of multiple representations is aimed at supporting cooperation and collaboration among accidentologists. At a lower level, as previously stated, representation management is aimed at coming to a mutual understanding *and* to a mutual agreement on the interpretation of a specific accident (and sometimes on a thematic analysis of several accidents).

Case 003 illustrates that accidentologists also manage representations to come to an agreement on the interpretation of an accident. Accidentologists want to convince their partners of the soundness of their interpretation, or they want to be convinced. For instance, arguments are exchanged to decide which factors to include in the synthesis of the accident case. Table 1 presents the contents of the individual and collective representations of Case 003 factors mentioned by the accidentologists. Columns "E-psy1" and "E-infra3" refer to the individual representations of experts E-psy 1 and E-infra3 at the beginning of the task of elaborating a common list of accident factors (the individual representation of E-veh2 is not included because this representation was provided by E-veh2). Column "Trio" refers to the collective (shared temporary) representation resulting from the discussion between the three experts E-psy 1, E-veh2 and E-infra3, at the end of the same task. It can be noticed that this final shared temporary representation is very close to the initial non-shared representation of E-psy1.

4.2 Operations and Tools of Representation Management

To achieve mutual understanding and mutual agreement, agents perform various operations of representation management with different tools. In the context of software design teams, Ostwald indicates that designers and users perform operations such as *creation*, *accumulation*, *structuration* and *discussion* of representations. As components of the three knowledge construction processes, Ostwald focuses on activation of existing knowledge (for making explicit some tacit knowledge), communication (for accumulating and updating common ground) and envisioning (for deciding what ought to be).

In her study of a voice dialogue design team, Sumner (1995) reports on more specific operations, for example maintaining consistency across (or managing the co-evolution of) the various design Tepresentations. This operation is important because: (a) there are complex relationships between the representations; (b) this interdependency evolves as the design progresses; and (c) many design errors, as shown by empirical studies (e.g. Guindon, Kramer & Curtis, 1987), result from designers' cognitive limitations when managing the dependencies across representations.

With regards to the tools used by agents to perform the operations mentioned above, Sumner reports that designers assemble a collection of software tools, referred to as the "toolbelt", and use them to create different design representations, e.g. a

Table 1: Individual (E-psy1 and E-infra3) and collective (Trio) representations of case 003 accident factors

Factors	Representation Content Elements	Representations of E-psy1	E-infra3	Trio
Infrastructure	*Nissan Sunny and R21*			
	Three-lane road without direction of allocation for the middle lane ⟹ conflict between overtaking and turning left (use of the central lane).	x		x
	Blurred procedure of use for left turn.			x
	Three lanes — easy layout — straight lines ⟹ high speeds possible.		x	
	R21			
	Rectilinear infrastructure ⟹ prompts to drive fast.	x		x
	Cut in zone ⟹ prompts too close overtaking.	x		
Driver	*Nissan Sunny*			
	Focus of the activity is to reach the gas station ⟹ strong constraint: possible breakdown.	x		x
	Focus of attention on the traffic across the road.	x		x
	Problem of evaluating the speed of the R21 as it gets closer **(speed differential)** combined **with slowing-down speed of the R21 (speed regulation).**	x		x
	Little knowledge of the itinerary ⟹ no knowledge of the next possible exit for a gas station (a few gas stations further away).		x	
	R21			
	Errors of interpretation of the intention of the Nissan.	x		x
	When sees the indicator, thinks that the person wants to overtake ⟹ influence on the regulation of the speed. Thinks that he will let the car overtake.	x		x
	Knowledge of the cut in zone ⟹ the overtaking goal temporarily takes priority over the security goal.	x		x
Vehicle	*Nissan Sunny*			
	Under-inflated tyres.		x	
	R21			
	Brake disks completely bare.		x	

word processor to create text documents, a flowcharting tool to create flowcharts, a database to create tables.

As we will see, the operations and tools described by Ostwald and Sumner can be applied to the accidentology teams to a certain extent, and thus some adaptation and completion are necessary. With regards to the tools, we observe that different software tools are also used by accidentologists, for example to create, modify and exchange external representations, e.g. *CorelDraw* for creating plans of the accident site, *MS Word* to create texts and tables, *Paradox* for creating databases, *Anac2D* for elaborating simulated trajectories of vehicles, before, during and after the crash (*Anac2D* also allows adjustments of various vehicle parameters, and visualisation of the vehicle movements) (see Lechner *et al.*, 1986; Lechner & Ferrandez, 1990).

As for the operations, it can be said that accidentologists, for example, create, accumulate, structure and discuss representations. More specifically, maintaining consistency between representations is a major characteristic of accidentologists' activity. For instance, vehicle engineers explicitly search for coherence of accident scenarios when performing kinematics reconstruction. Coherence of each "individual scenario" (a scenario for each vehicle involved in the accident) and coherence of the "global scenario" (a scenario including all the vehicles involved in the accident). However, Ostwald's framework must be adapted and complemented to account for the operations performed by the accidentologists: some operations need to be specified, while others need to be added. Some directions to adapt and complement the description of operations are suggested below.

Direction 1. To refer to operations described elsewhere, e.g. to the knowledge construction operations proposed by Norman (1982) in his cognitive model of learning: *accretion* — to acquire new information, *restructuring* — to integrate the acquired information into agents' existing knowledge structure, and *tuning* — to assure a "smooth operation" of the knowledge structure, since any increase in knowledge is a change that has rippling effects through the knowledge structure (see also Rumelhart & Norman, 1981). Note that these operations only concern internal representations but they can be extended to external representations. In accidentology, tuning can take the form of "popularisation", i.e. rendering a specialised representation intelligible to non-specialist agents, and consequently making the representation shared.

Direction 2. To specify what, in the representations, is the object of operations. For example, if representations are said to be composed of data (Tabachneck et al., 1997), operations can be data acquisition (to infer internal representations of the others), and data exchange (to make internal representations explicit). For instance, some accidentologists could make their view explicit on the terminology of other experts (in particular, on the notions of scenario and of factor). In the collective analysis of Case 003, we have an example of the psychologist explicitly requesting from the infrastructure engineer information or explanations on the meaning of some infrastructure terms.

Direction 3. To distinguish operation descriptions in terms of the representation type they handle. In particular, a distinction could be made between *topic representations* (or representations) and *control representations* (or *meta-representations*). Topic representations are those representations that are under discussion, e.g. the scenario of the accident currently analysed. Control representations are those representations that guide operations on topic representations, e.g. the DVI system model, the functional model and the model of decomposition into phases to help construct the accident scenario. Thus, the maintenance of the notion of consistency across representations could be split into maintaining consistency of topic representations and maintaining the consistency of control representations. An example of the latter is the maintenance of the notional consistency. We will illustrate this by some uses of the notions of "scenario" and "factor".

- *Scenario*. E-psy1 makes a distinction between the spatio-temporal scenario of the accident and the typical scenario of the accident. E-psy2 distinguishes between the scenario and the process of the accident. E-veh1 distinguishes the typical scenario and the typical accident, and makes references to the complete kinematics scenario. E-veh2 refers to the generic scenario and the global scenario. Both vehicle engineers use the notions of first scenario and individual scenario. E-infra1 distinguishes the typical scenario (defined as a class of accidents), the permanent scenario and the *ad hoc* scenario. E-infra3 makes a difference between the family scenario and the history scenario.
- *Factor*. E-psy1 classifies factors as potential, terminal, aggravating and triggering. To the more classic notion of causal factor, he prefers the notion of initiator or explanatory element. E-psy2 emphasises the distinction between the factor (i.e. a static notion) concerning the components of the DVI system, and the failure (i.e. a dynamic notion) which takes into account the interactions between at least two of the components. Finally, E-infra1 makes a distinction between the factor and the mechanism of the accident.

Direction 4. To specify the operations in terms of the characteristics of the representations that are operated, and especially in terms of the important characteristics, i.e. those which are necessary to achieve the representations management goals. Maintaining consistency is an example of such a specification. Another example is maintaining the accuracy of representations. Sometimes the data collected by trainees or non-experienced investigators are not accurate enough for the experts to use them in their thematic studies. Thus, there is a need to train investigators to fill in the checklists better and more efficiently. That would help, not only the investigators themselves, but also the experts. Furthermore, it also means that a better communication between investigators and researchers would result in a greater closeness of representations among these two groups.

Another example is maintaining the plausibility of representations. For example in the first phase of one accident case study, one accidentologist had an hypothesis upon which he had built his reasoning. In phase two, discussions with the other accidentologist took place, and this other accidentologist used the kinematics reconstitution to demonstrate that this hypothesis was in fact wrong.

4.3 Factors Determining Multiple Representation Management

To account for the management of multiple representations in accidentology situations, we also need to identify the factors which determine it.

4.3.1 Agents' Goals

A first factor has been already mentioned. It is the goals pursued by the agents, in particular the understanding and agreement goals. These goals can be considered as meta-representations. Since the goals are multi-levelled and distributed among agents, a difficulty in multiple agent problem-solving situations is that of the matching of the agents' goals.

When constructing specific accident folders, investigators or researchers as investigators had different goals in mind. For example, in Case 003, the common goal of the researchers was to make a synthesis of the given accident. They had a goal of integration, that is, to find common elements to make this synthesis. Researchers also had individual goals such as to hold on one's own point of view, or to take minutes of the session and so on.

Other goals to be considered are problem-solving and learning goals. When an expert analyses an accident (either collectively or individually), he is usually in a problem-solving mode. In the data collected in accidentology, we cannot talk about learning goals as such. Learning had mainly been incidental, or by doing (George 1983), resulting in new permanent representations. By doing, i.e. by performing some accident analysis action, and by evaluating the consequences of the action, the experts got feedback that led them to learn incidentally about the accident analysis task. Learning occurred when, for example, experts from different specialities have to analyse a case together, e.g. when the expert E-psy2 learns about the coding system of the infrastructure file. In another example, the infrastructure engineer E-infra3 who often works in real life with the psychologist E-psy2 was influenced by this psychologist and made for instance references to cognitive models of the driver, models adapted for his own use.

The issue of the agents' goals as a determinant of representation management could be also studied through Clark's (1992) grounding criterion, which states that speakers, to establish common ground, produce a representation allowing the partners to understand what is meant "to a criterion sufficient for current purposes".

4.3.2 Agents' Background Knowledge

In section 2, we have seen that agents produce and interpret representations "within a social context and against their individual background" (Ostwald, 1996). Background refers to the knowledge of the agents, especially their speciality knowledge. The agents' background may determine the type of representations that can be produced and understood. For example:

- Psychologist E-psy1 has been working on a typology of the drivers' errors and his analysis of traffic accidents was based upon it. E-psy2 has performed thematic studies on specific types of drivers such as old people and drivers on cross-roads. In addition, he was very interested in vehicle mechanics. Both psychologists have been living in the region for years and know the characteristics of the region infrastructure very well.
- Vehicle engineer E-veh2 has a more theoretical background and developed *Anac2D*, the software tool for kinematics reconstitution. E-veh1 uses *Anac2D*. Both engineers also know the features of the roads in the region very well.
- E-infra1 has a very deep theoretical background and has worked on a theoretical model of accidents. As he lives in another French region (Eure-et-Loire), he does not know the features of the region infrastructure as well as the other accidentologists who have been living in the region for years. E-infra2 and E-infra3 are both very interested in mechanics and vehicles. One of them, E-infra3 is also interested in the psychological analysis of the drivers, even though it is not his discipline.
- In addition to the expertise of their own speciality, the accidentologists have gained a tremendous know-how from their past experiences related to: (a) their active participation as investigators, in the past or even currently (for the psychologists, for some of the vehicle engineers and some of the infrastructure engineers); (b) their past thematic analyses as mentioned above.

4.3.3 Agents' Status

Besides the individual background is the social context. The social context refers, for example, to the agents' *status*. *Status* can be defined as the permanent or circumstantial situation of an agent within the group. Here are some examples of the agents' *status* as determinants of representations management:

- Psychologists have the permanent *status* of driver specialists. Thus, the driver-related representations they use can be considered as the most relevant ones to explain drivers' behaviour.
- Vehicle engineers have the strong permanent status of "pillars" of accident analysis: the kinematic reconstruction they perform, and the *Anac2D* tool they use (which helps them reconstruct the kinematics of the accident, thus providing *scientific* data), are the "guarantors" of the plausibility of the accident interpretation.
- *Circumstantial status* can sometimes prevail on the permanent status. For example, in the Case 003 situation, we found that the result of the integration of representations of the list of factors was predominantly guided by a "leading" member of the group, namely by the psychologist E-psy1 (see Table 1).
- A special case of the role of the agents' status is worth mentioning here: it is the status of the drivers as partners of accidentologists in accident analysis. We can distinguish partners face-to-face and in real time (in the case of the drivers with the investigators interviewing them), and distant partners and at a later point in time

(in the case of drivers whose interviews are analysed by the researchers later on after the accident has occurred). Drivers provide their representations of the accident: e.g. they verbally report their view of the accident. Accidentologists, especially psychologists, often question the reliability of the drivers' reports, because they have often to face drivers who lie, or at least transform the reality (about their driving speed for example), to minimise their responsibility. Psychologists then feel the need for a kinematics reconstitution to test the reliability of the drivers' statements.

4.3.4 Agents' Styles and Perspectives

Perspectives have been defined by Bromme (1997) as the "epistemic styles typical for a discipline or a domain of research activities". As indicated above, some researchers use abstract, formalised representations, while others use more concrete and down-to-earth representations. This results in having, at one end of the spectrum, very formalised representations and, at the other end, more concrete and down-to-earth representations. For example, in the Case 003 situation, the psychologist E-psy1 used a formalised functional model of the driver. In the transcript of this particular session, the theoretical thinking process of E-psy1 was clearly displayed.

4.3.5 Agents' Preferences

Agents' interests can determine representation management. This interest can be triggered by the use of some representation by some other agent. For example, in a case study where the psychologist E-psy2 worked collaboratively with an infrastructure engineer who used photos intensively to analyse the accident, we observed that E-psy2 came to use more photos to obtain cues explaining the accident, although he previously searched for these cues in the checklists.

4.3.6 Agents' Terminologies

Within the context of the multiple representations, the experts use various vocabularies and terminologies. Indeed, each speciality has its own terminology (see the examples given in section 4.2). Experts might share terms with other experts (from another speciality or from the same one) specifically at the abstract level. However, their terminologies become more specific and specialised at the detailed levels. With respect to the different types of terminology divergences studied (Gaines & Shaw 1989; Shaw & Gaines 1989), we only found examples of "terminology conflict", i.e. several experts giving different meanings for the same term.

4.3.7 Cooperation

In our studies in the accidentology domain, we can distinguish different types of cooperation.

- "Immediacy" of the agents' cooperation which incorporates direct collaboration and indirect collaboration proposed by Ostwald (1996).
- Indirect collaboration occurs when knowledge or products are shared through some persistent medium, such as a database or other repository. Indirect collaboration is required when direct (face-to-face) collaboration is not possible or impractical. Long-term collaboration takes place over arbitrary time frames, and also requires some persistent medium in which knowledge or products can be stored.

In accidentology, the case of indirect collaboration between investigators and researchers is worth considering. For their thematic analysis, the researchers analyse the brief elaborated by the investigators. Often the brief does not describe everything explicitly, so that researchers lack some information important for their work, e.g. information about some specific contextual element of the accident, or information about the investigators' reasoning for elaborating the conclusions of the brief. When the investigators who elaborated the brief are still present in the Department of Accident Mechanisms, they can be consulted by the researchers. The problem arises when the investigators have left the department and are no longer available; the information is then lost. To prevent such information loss, researchers are currently looking for means of having the investigators collect information that might be needed in the future.

Another case of indirect cooperation is what can be called "understanding a third party". For example, the cognitive models of the driver explicitly used by the psychologists and by the infrastructure engineers could serve as a framework for interpreting the analyses carried out by the other accidentologists about the component and its interactions with the other components, even though these other accidentologists do not explicitly evoke these models.

The issue of indirect cooperation can also be studied in terms of agents' responsibility, as defined by Clark (1992) in the context of conversations:

Principle of responsibility. In a conversation, each of the persons involved is responsible for keeping track of what is said, and for enabling the other persons of keeping track of what is said.

When writers or speakers are distant from their addressees in place, time or both, they are assumed to adhere to the principle of distant reponsibility:

Principle of distant responsibility. The speaker or writer tries to make sure, roughly by the initiation of each new contribution, that the addressees should be able to understand his meaning, in the last utterance to a criterion sufficient for current purposes.

We could say, for example, that to make their indirect cooperation with researchers successful, investigators must adhere to the principle of distant responsibility.

- Intra- and inter-cooperation: another way to look at cooperation in accidentology teams is in terms of a cooperation intra-role — between investigators or between experts; and a cooperation inter-role — between experts and investigators.

Cooperation between investigators. Investigators work at the site of the accident, and do work in a cooperative manner. For example, (i) they share the tasks, i.e. one carries out the interviews, and the other one collects information about the vehicles and the infrastructure; and (ii) they exchange information and points of view. The result of their cooperation is in a way implicitly recorded in the accident brief they have to prepare.

Cooperation between the researchers. During the analysis of the accident, all the experts share a common focus, i.e. to understand how the accident happened and to identify the accident-related factors. However, each expert has a responsibility to analyse the causes of a given accident in his own speciality, and thus will have specific sub-tasks (corresponding to his speciality) in order to bring his contribution to the common goal. Furthermore, experts will have different goals when they examine accident cases from thematic perspectives.

The cooperation in the accidentology team can be characterised as "they need each other". Typically, an expert researcher will work individually on a given accident, and will exchange information with his colleagues (from the same speciality or from another one) when he needs some data. For instance, the expert psychologist will ask the vehicle engineer about the speed of the car at the time of the accident in order to confirm or disconfirm an hypothesis. Although the expert psychologist may already have guessed at the speed, the vehicle engineer will provide accurate data.

Cooperation between the researchers and the investigators. A cooperation between experts and investigators can happen when for example an expert seeks additional information about a given accident. To do so, he has to contact the persons who wrote the report.

5 Conclusion

In this chapter, we have explored multiple representations in groups which can be found in real and complex situations of accident reports involving accidentologists from INRETS. As a theoretical framework we chose Ostwald's model of "representations for mutual understanding". Ostwald proposes an approach to cooperative software design that emphasises the construction of representations to facilitate communication among partners, or artefacts for constructing shared understandings.

From our analyses, a number of dual dimensions of multiple representations emerged such as representations which are internal external, abstract concrete, permanent temporary and shared non-shared. This latter dimension seems to be the most crucial one to account for multiple representations in groups. Furthermore, it was also found that representations used in the accidentology teams are not only for mutual understanding, but also for mutual agreement. "Speakers" use representations to explain (some accident) or to convince (about some accident interpretation); while "addressees" use them to understand or to be convinced.

Given these various types of multiple representations used in accidentology teams, we described the management of multiple representations which aims at supporting collaboration and cooperation among accidentologists. To achieve mutual understanding and mutual agreement, agents perform various operations of representations management with different tools. One of the major operations we found is that of maintaining consistency between representations. To account for the management of multiple representations, we have also identified a number of factors such as the agents' goals, background, status, styles and perspectives, terminologies and preferences.

Our results from the study of multiple representations in accidentology have consequences on several issues of multiple representations evoked in this volume. To close this chapter, we will briefly present two of these consequences.

5.1 Dissimilarity of Representations

The notion of multiple (or distributed) representations has been defined by Boshuisen and Tabachneck-Schijf (chapter 8) as "the circumstance where multiple human or artificial agents have dissimilar representations about one object, person, interaction or situation." Boshuizen and Tabachneck-Schijf notice that this dissimilarity (defined in terms of representations data, formats, or operators) "can be the source of many misunderstandings." Our results also suggest that we can describe the effects of representation dissimilarity in terms of "disagreements" — unless the term "misunderstanding" is used *largo sensu*, as referring also to "the act of disagreeing" (on-line *Webster's Dictionary*).

5.2 Representations and Common Ground

The notion of "common ground" (Clark, 1992; Clark & Brennan, 1991), used for example by Bromme and Nückles (chapter 10) to account for multiple representations in multiple agents' communication, deals with understanding aspects, not with agreement aspects of multiple agents' communication — unless the term "understanding" is used *largo sensu*, as referring also to "a mutual agreement not formally entered into but in some degree binding on each side" (on-line *Webster's Dictionary*). Our results suggest that the notion of common ground could deal with agreement aspects as well.

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